

DESALINATION BY ELECTRODIALYSIS USING A STACK OF CHARGED HYDROGELS IN A MICROFLUIDIC PLATFORM

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ABSTRACT

We show a new approach for desalinating water, using a stack of periodic hydrogel structures in a microfluidic platform. This technique utilizes alternating anion- (AEH) and cation-exchange hydrogels (CEH) locally fabricated in confined compartments by capillary line pinning. Parallel streams of concentrated and ion-depleted water are formed in continuous flow when applying a potential difference across the microchip. Different electric fields (10-100 V/cm) and fluid flow rates (0-5 $\mu\text{l}/\text{min}$) are investigated.

KEYWORDS: Desalination, charged hydrogels, capillary line pinning, microfluidics.

INTRODUCTION

Microfluidics has been used for downscaling the electrodialysis process to increase energy efficiency and water recovery. Building hybrid membrane microsystems has been a special focus, as such systems can reduce the energy consumption by decreasing the membrane resistance. Recently, the integration of hybrid membranes in microdevices was demonstrated for charge-based separations.[1] These microdevices contained one microchannel sandwiched between ion exchange membranes, often leading to fluid leakage.[2-4] Our desalination microdevice overcomes this complication by combining microfluidics and charged hydrogels patterned by capillary line pinning, and it can increase the overall performance of desalination process thanks to its highly-parallelized nature.

EXPERIMENTAL

Microchips were fabricated from polydimethylsiloxane (PDMS) using standard soft lithography. Design and fabrication details of capillary barriers were previously introduced by our group.[5,6] Microchips contained pillars, capillary barriers, microchannels, and fluidic connections. Microchannel and capillary barrier heights were 75 and 7.5 μm , respectively. Each hydrogel compartment (200x500 μm), is interconnected to another via microchannels. An assembled microchip is shown in Fig.1a. For AEH, 1%(v/v)[2-(methacryloyloxy)ethyl]trimethylammonium chloride solution; and for CEH, 1%(w/v)3-sulfopropyl acrylate potassium salt were added to a polyacrylamide precursor, the recipe of which can be found in Ref. 5. Hydrogels were patterned by simply injecting the degassed solutions into the microchip and photopolymerizing by UV exposure. A blend of 10 μM NaAlexaFluor and 1 mM NaCl solution was pumped through the microchannels, and the voltage was applied using two gold-coated electrodes placed in the middle of outer microchannels (Fig.1b). Sample concentration was determined by impedance measurements.

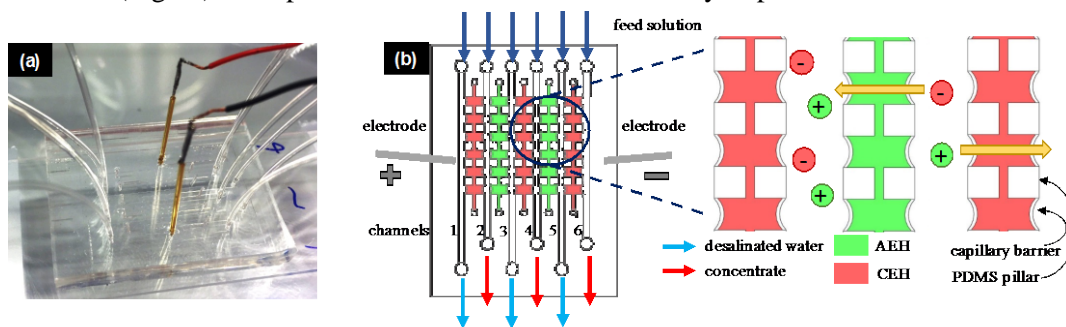


Figure 1: (a) An image of the assembled microchip. (b) Schematic top view of the microchip and the working mechanism.

RESULTS AND DISCUSSION

The working mechanism for desalination is shown in Fig.1b. Microscopically measured pore sizes of hydrogels were in order of a few nanometers. Ion exchange capacity was measured by titration experiments as 1.4 mmol/g_{dry} for AEH, and 0.31 mmol/g_{dry} for CEH. The swelling capacity of both hydrogels is ~15%. These characteristics make the hydrogels suitable to induce desalination without any swelling or low ion-transport rate problems. In the microchip, ion depletion and enrichment regions were observed under application of 0-1.5 V/cm electrical fields in the absence of flow (Fig.2a-c, see also Fig.4). Vortex formation was also observed when 3 μ l/min flow rate was applied with 10 V/cm (Fig.2d-f) and 15 V/cm electric fields (Fig.2g-i). Fig.3 illustrates the desalination performance of the microchip under different NaCl concentrations, electric fields and flow rates. In this work, for the first time, hydrogels were shown to perform desalination in a hybrid and parallelized platform.

CONCLUSION

Our approach is promising for development of a low-cost and hybrid hydrogel system for efficient desalination of brackish water. The simplicity of this novel platform may enable widespread adoption in electro dialysis technique.

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REFERENCES

- [1] L. J. Cheng, H. C. Chang, *Biomicrofluidics*, 5, 046502, 2011.
- [2] R. Kwak, G. Guan, W. K. Peng, J. Han, *Desalination*, 308, 138, 2012.
- [3] R. Kwak, V. S. Pham, K. M. Lim, J. Han, *Phys. Rev. Let.*, 110, 114501, 2013.
- [4] S. C. Park, D. Taek, H. C. Kim, *Microfluidics Nanofluidics*, 6, 315, 2009.
- [5] B. Gumuscu, A. van den Berg, J. C. T. Eijkel, *μ TAS Proceedings*, 1695, 2014.
- [6] B. Gumuscu, A. van den Berg, J. C. T. Eijkel, *Lab Chip*, 15, 664, 2015.

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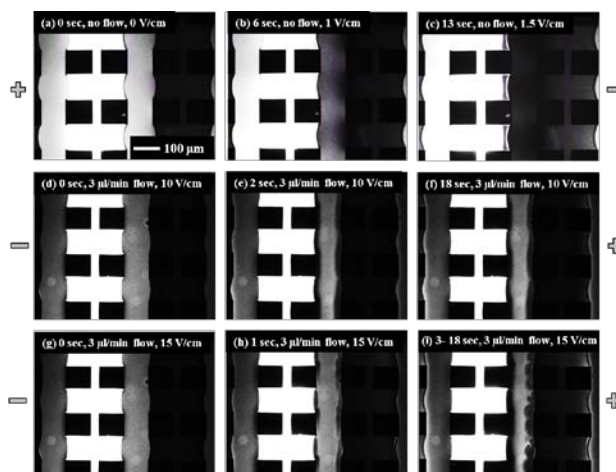


Figure 2: Fluorescence images of ion concentration polarization in the microchip. 0.1 mM NaCl solution with 10 μ M NaAlexa (the fluorescent dye) was injected into the microchip and an IV sweep up to 3V was demonstrated. The experiments performed (a-c) under increasing electric field at no flow, (d-e) at 15 V/cm and 3 μ l/min flow rate, (g-i) at 10 V/cm and 3 μ l/min flow rate. The bright colored hydrogel is AEH and the dark colored one is CEH. Plus and minus signs represent the signs of the electrodes.

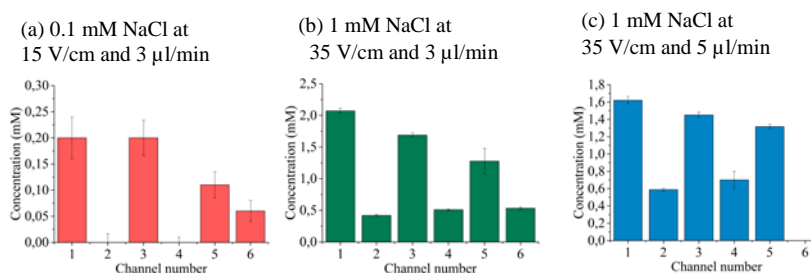


Figure 3: NaCl concentration at separate channels (a) Initial NaCl concentration is 0.1 mM under 15 V/cm electric field and 3 μ l/min flow rate. Channels 2 and 4 are completely, and channel 6 is partially desalinated. (b) Initial NaCl concentration is 1 mM under 35 V/cm electric field and 3 μ l/min flow rate. Channels 2, 4, and 6 are partially desalinated. (c) Initial NaCl concentration is 1 mM under 35 V/cm electric field and 5 μ l/min flow rate. Channels 2 and 4 are partially desalinated. See Fig.1 for the channel numbers.

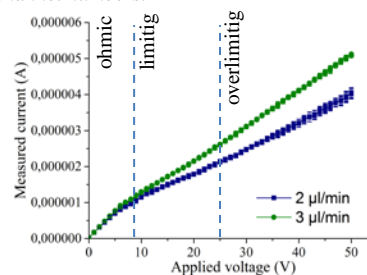


Figure 4: Current voltage curve of the microchip system when 2 and 3 μ l/min flow rates are applied. The graph clearly shows the limiting, ohmic and overlimiting regimes.